Table 3. Coral reef metrics that show a quantitative change in attribute value across a gradient of human influence that is reliable and interpretable and that have been calibrated for specific locations.

Metric/ Impact	Parameters	Status	Reference/Location
Calibrated Numerical Coelobite Index/ Drilling discharges	Points assigned for presence - absence & abundance of certain important coelobite groups (i.e., *Homotrema rubrum*, other encrusting foraminifers, boring sponges, non-boring sponges, scyphozoans, bryozoans, molluscs, & serpulids). Points also given for the number of *H. rubrum* plus bryozoan colonies/ 100 cm^2.	Potential for monitoring sedimentation on coral is untested	Choi, 1982/ Pacific - Philippines
Gastropod Imposex - RPS Index/Tributyltin	Frequency of imposex (imposition of male sexual characteristics on female marine snails) in females and relative penis size	Fully developed	Ellis and Pattisina, 1990/Caribbean, Pacific, Indian
Nitrogen Isotope Ratios in Reef Organismal Tissues/Human sewage	Tissues of reef corals from sites with heavy human sewage inputs showed significantly higher $\delta^{15}N$ (ratio of $^{15}N/^{14}N$) values than coral tissues from relatively "clean" sites.	Calibrated for Indonesian and Jamaican coral reefs; further comparative work needed to test applicability to other geographic regions.	Risk et al., 1994; Dunn, 1995; Heikoop, 1997; Risk & Erdmann, 2000/Indonesia (Zanzibar, Maldives) Lapointe, 1999/Negril, Jamaica

Coral Damage Index/Coral physical damage	Sites are listed as "hot spots" if in a transect the percent of broken coral colonies is greater than or equal to 4% or if the percent cover of coral rubble is greater than or equal to 3%.	Fully developed	Jameson et al. 1999/Red Sea
FoRAM Protocol	The protocol consists of the following: sediment analysis, analysis of live larger foraminiferal assemblages, and *Amphistegina* foraminifera population analysis including abundance, presence of bleaching, and other evidence of specific stressors.	Further dose-response research using *Amphistegina* is in progress. Further comparative work needed to test applicability to other regions. Not transformed into an index.	Hallock, 2000/Florida Keys

Where Do We Go From Here?

Creating A Diagnostic Monitoring Program Using the Biocriteria Process

The first step toward effective diagnostic coral reef monitoring is to realize that the goal is to measure and evaluate the consequences of human actions on coral reef systems. The relevant measurement endpoint for coral reef monitoring is biological condition; detecting change in that endpoint, comparing the change with a minimally disturbed baseline condition, identifying the causes of the change, and communication of these findings to policymakers and citizens are the tasks of biological monitoring programs. Understanding and communicating the consequences of these human-induced ecosystem changes to all members of the human community is perhaps the greatest challenge of modern ecology (Karr and Chu, 1999).

The use of multiple measures, or metrics, to create indexes of biological integrity and biocriteria is a systematic process involving discrete steps. Jameson et al. (1998) and (Gibson et al., 1997) describe this process in detail and it is summarized in Table 4.

Table 4. Sequential progression of the biocriteria process.

Step 1	Preliminary classification of the coral reefs to determine reference conditions and regional ecological expectations - Coral reef classification - Determination of best representative sites (reference sites representative of class categories)
Step 2	Biological survey - Sampling along a gradient of conditions permits metric calibration and discrimination - Collection of data on biota and physical/chemical habitat - Compilation of raw data
Step 3	Final classification - Test preliminary classification - Revise if necessary
Step 4	Metric evaluation and index development - Data analysis (data summaries) - Testing and validation of metrics by coral reef class - Evaluation of metrics for effectiveness in detecting impairment - Aggregation of metrics into index - Selection of biological endpoints - Test the index for validity on another data set
Step 5	Biocriteria development - Adjustment by physical and chemical covariates - Adjustment by designated aquatic life use
Step 6	Implementation of monitoring and assessment program - Determination of temporal variability of reference sites - Identification of problems
Step 7	Protective and remedial management action - Initiate programs to preserve exceptional waters - Implement management practices to identify and address the causes of this degradation and to restore the biota of degraded waters
Step 8	Continual monitoring and periodic reviews of reference sites and biocriteria - Biological surveys continue to assess efficiency of management efforts

- Evaluate potential changes in reference condition and adjust biocriteria as management is accomplished

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Major Issues And Next Steps

Classifying Coral Reefs For Biological Monitoring

One of the most difficult challenges in creating IBIs and biological criteria for coral reefs is developing a workable classification system for natural systems that includes ecoregions (possibly subregions) and classes of sites (Jameson et al., 1998). The point of classification is to group coral reef natural systems by physical and biological community characteristics such that biotic responses are similar both in the absence of human disturbance and after human disturbance. Hypothetical examples of coral reef classes might be; windward central Pacific oceanic atolls, eastern Indonesian nearshore fringing reef slopes, or Caribbean lagoonal reefs. In some cases, these groupings may coincide with ecoregion boundaries; in others, they may cross those boundaries. To evaluate sites over time and place, we need groupings that will give reliable metrics and accurate criteria for scoring metrics to represent biological condition. The challenge is to create a system with only as many classes as are needed to represent the range of relevant biological variation in a region and the level appropriate for detecting and describing the biological effects of human activity in that place (Karr and Chu, 1999).

A coral reef classification system designed for diagnostic monitoring will be different than a classification system designed for the more traditional use of identifying conservation areas. Classification based on ecological dogma, on strictly chemical or physical criteria, or even on the logical biogeographical factors used to define ecoregions is not necessarily sufficient for biological monitoring. One must use the best natural history, biogeographic, and analytical resources available to choose a classification system (Karr and Chu, 1999). In freshwater streams, higher-level taxonomic and ecological structure usually provide better guidelines for classification than focusing primarily on species (Karr and Chu, 1999). In general, ecological organization and regional natural history are better guides for site classification and for signaling human disturbance than a focus on species composition. Once a coral reef classification system is proposed its usefulness must be tested using relevant metrics. The primary factors which make coral reefs biologically similar or different and that may be important in defining ecoregions and classes will be discussed in a future publication (Jameson et al. in prep.).

The Framework For The Definition Of Coral Reef Multimetric Indexes

Figure 1 shows the organizational structure of the types of attributes that should be incorporated into coral reef biological assessment. The framework is rooted in sound ecological principles and a similar version has been successful in freshwater bioassessment (Barbour et al., 1995). The use of each attribute is based on a hypothesis about the relationship between the coral reef condition and human influence. Multimetric indexes are generally dominated by metrics of taxa richness, because structural changes in aquatic systems, such as shifts among taxa, generally occur at lower levels of stress than do changes in ecosystem process (Karr and Chu, 1999). However, multimetric indexes also often include measures of ecological structure, frequency of diseased individuals, etc. and are broad in scope. Multimetric indexes can detect many influences in both time and space, reflecting changes in resident biological assemblages caused by single point sources, multiple point sources, and nonpoint sources. They can be useful in monitoring one coral reef or several, and they permit comparisons over a wide geographic area. The wide-ranging responsiveness of multimetric biological indexes makes them an ideal tool for judging the effectiveness of management decisions (Karr and Chu, 1999).